LIGHT AND THE ETHER.

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(*Read* 13*th May*, 1919.)

The wave theory of light was advanced by Huyghens towards the close of the 17th century. It gradually superseded the emission or corpuscular theory which had been held by Newton, but which was at variance with the fact that the velocity of light is greater in air than in denser media such as water and glass. The medium in which the light waves take place on Huyghen's theory is termed the aether—a subtle fluid which permeates all space. And since the velocity of light in air is the same as that of an electromagnetic wave in air, it is concluded that light itself is an electromagnetic wave. This conclusion has been generally accepted as the result of Hertz's experiments and Clerk-Maxwell's mathematical investigations.

The velocity of light has been determined in a variety of ways:—1. From Römer's observations of the acceleration and retardation of the times of occurrence of eclipses of Jupiter's satellites depending upon the varying distance of the Earth from Jupiter. 2. From Bradley's investigation of the aberration of light—light appearing to come from a direction slightly different from the true direction in consequence of the Earth's motion (the effect is strictly analagous to the phenomenon of vertically falling rain appearing to come obliquely from in front against a person moving through it). 3. From experiments by Foucault, Fizeau, Forbes, and others on the time taken by light to travel over a measured distance not exceeding a few miles.

In Bradley's investigations of the aberration of light, it was shown that a telescope used in observing a star was always slightly inclined to the true direction of the star by an amount depending upon the ratio of the Earth's velocity to the velocity of light. The theory assumed that the aether was at rest while the observing telescope and the contained air moved through it. As the experiment gave a result in harmony with those of other methods, this assumption was evidently justified. Airy, however, repeated Bradley's experiment with the telescope filled with water. Since light travels in water with only three-fourths of its velocity in air, the aberration should have been correspondingly greater. It was found, however, to be quite unaltered. Apparently, then, air moves freely through the aether, but water drags the aether along. Fresnel made a mathematical investigation of this aether drift, and his resulting formula was afterwards verified by an ingenious experiment due to Fizeau, in which two rays of light were sent along the same path, one with and one against a stream of water, that is, one with and one against the resulting aether drift.

If V is the speed at which a swimmer travels through the water of a river flowing at velocity v, then the swimmer will be able to travel up, down, and straight across the river at speeds which are respectively $(V - v)$, $(V + v)$, and $\sqrt{(V^2 - v^2)}$. Hence if the river is of width s, the time T_1 taken to swim across and back is $2s / \sqrt{(V^2 - v^2)}$, and the time T_2 to swim distance s up or down the river and back is $2V s / (V^2 - v^2)$. That is, we have

$$T_1 : T_2 :: V : \sqrt{(V^2 - v^2)}.$$

But V is greater than $\sqrt{(V^2 - v^2)}$ for all possible values of V and v, and thus the time for a certain journey up and down stream is always greater than for the same length of journey across stream. For example, a person who swims 2 miles per hour will take less than 3 mins. 28 secs. to cross and re-cross a river four chains wide flowing at one mile per hour. He will, however, take 4 mins. to do the same length of double journey up and down the river.

Now, as the Earth is moving relatively to the Sun, and the Sun relatively to other members of the sidereal universe, our Earth is evidently in general travelling through the aether, or, the aether has a drift relative to the Earth. And for light travelling at velocity V through an aether drift of magnitude v, the time for the double journey along the line of aether drift must be greater than the time for a path of equal length at right angles to, that is athwart, the aether drift. Michelson and Morley attempted to test this by experiment. They sent a ray of light along a certain path and reflected it back to the point from which it set out. Another ray was sent an equal distance along a path at right angles, and any minute difference in the times taken by the two rays to return could be easily ascertained by a delicate interference test. The two rays were found to take precisely the same time. As this was contrary to theory, it was clear that the path which was across the aether drift must really have been longer than the path which lay along the aether drift. Now these paths were along rigid iron arms attached to a vertical stand floating in mercury. The apparatus could thus be rotated through a right angle so that the path which formerly was along the aether drift was now across it, and vice versa. But on repeating the experiment in this new position there was found again to be no difference in the times taken by the rays to cover the two paths. Only one conclusion appears possible—the rigid arms altered in length, shortening when turned into the direction of the aether drift and lengthening when turned at right angles to it! Remarkable as is this conclusion, there is no escape from it, and scientists now accept the fact that our standards of length—the standard yard kept in London and Borda's standard metre—change in length from time to time as the Earth changes its direction of motion through space and through the aether, or as these bars are turned about in the laboratories in which they are kept. We have no means of measuring our speed relative to the aether. For all we know to the contrary our Earth may at the present instant have a speed of, say, 100,000 miles per second relative to the aether. If it has this velocity, then a man who is 5ft. 8in. high when he stands up at right angles to this relative motion will be only 4ft. 9in. in height when he lies in the direction of the motion. We could not tell this difference by the eye, because the retina of our eye would have undergone a similar contraction in the same direction and the image of the 4ft. 9in. man would cover the same proportion of the retina in that direction as the image of the 5ft. 8in. man would cover in the other direction. We fail to observe this actual change which takes place in the dimensions of what we call rigid bodies, not because it is possibly small (it may be great as a matter of fact), but because it is of such a character as to baffle all ordinary tests, although it is revealed indirectly by such peculiarly applied tests as the Michelson-Morley experiment. The change will not appear just so difficult for us to admit when we remember that in all probability the forces of cohesion which bind together a rigid body are of the nature of electrical forces and thus act through the aether with its drift relative to the rigid body.

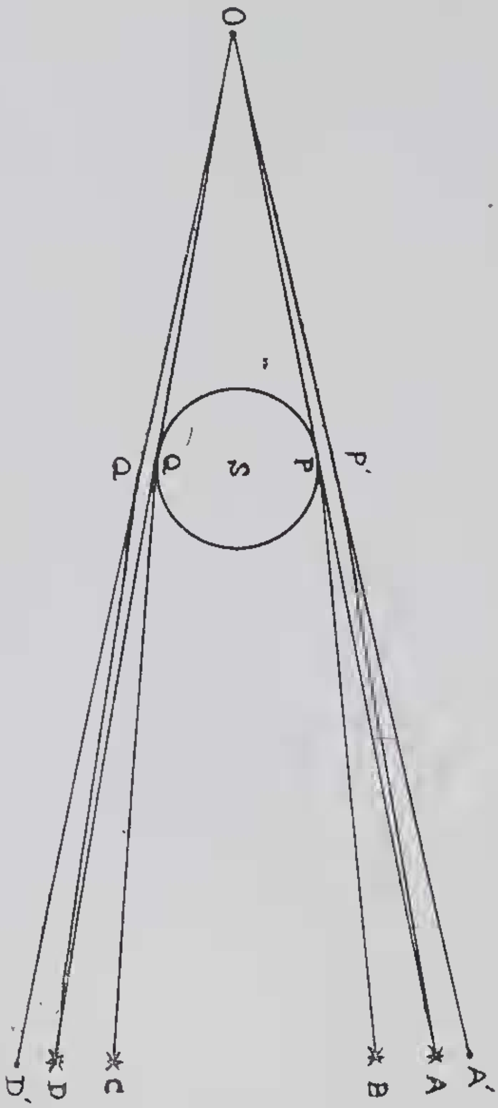
We commonly speak of space as having three dimensions, the directions which we popularly term up-and-down, to-and-fro, right-and-left. We can, however, imagine a flat or two-dimensional universe inhabited by flat beings who would fail to realise what was meant by the third dimension of up-and-down. And mathematicians find it just as easy to make calculations for four dimensions as for only three. It is possible for us, therefore, to imagine a model (we cannot actually construct it) which would introduce a fourth dimension. In a two-dimensional diagram we can show in a graph how the lengths and widths of rectangles of the same shape as this page are connected. In a three-dimensional model we could show how the lengths, breadths, and thicknesses of books of similar shape to this volume are connected. And in a four-dimensional model we could show in the same way how the lengths, breadths, and thicknesses of the volumes of Proceedings of this Society had varied at different times. The mathematician can, therefore, picture a model in which are indicated by distances in four directions, mutually at right angles, what we may call length, breadth, height, and (say) time. But owing to the curvature of the surface of our spherical Earth, the direction which we call in Perth purely height is a direction in space which is equivalent partly to height and partly to (say) breadth in Sydney, and equivalent partly to height and partly to (say) length in Roebourne.* Now Minkowski has used the fourth dimension of the nature of time as being of the same essential character as the others, and so while what we happen to regard as purely height in Perth may be regarded as purely breadth in Cape Colony, it might be regarded as of the nature of time in some other world possessing a velocity different from that of our Earth. The four-dimensional construction is very convenient as connecting together what we term position (or space) and time, so that a graph in it gives the whole history of progress of a particle in our universe, what we term the "world-line" of the particle. This four-dimensional world is spoken of as Minkowski's space-time world, and we gather from it that it is impossible to obtain an absolute separation into space and into time, but only a relative separation made to suit the particular observer. In Minkowski's own words, "Henceforth space and time in themselves vanish into shadows, and only a kind of union of the two preserves an independent existence." This idea is referred to as the principle of relativity, and we picture the aether as a four-dimensional continuum filling uniformly Minkowski's space-time world. In short the position is this, that just as we have regarded such properties as the colour and scent of a rose as dependent on the acuteness and accuracy of the observer's senses of sight and smell, so we must regard all ideas of form, position and time as purely relative and as varying for observers on different worlds having different motions relative to the aether. Time is no more absolute than our ideas of taste, touch, smell, colour and sound.

All observation consists in the recording of coincidences. For example, in measuring the size of a microscopic object we note the coincidence of the ends of the object with two lines on two scale divisions in a micrometer eyepiece. Hence as the world-line of a particle gives its full history, observations are merely the discovery of intersections of these world-lines, and we know of the action of a force on a particle by the deflection produced in the world-line of the particle. When there is no external action, the world-line runs straight. The gravitational influence of a particle throughout its neighbourhood, which leads to it affecting other particles and deviating their world-lines, has been accounted for on a theory which, while it in no way explains the cause of gravitation, brings that action for the first time under the same rationale as other forces. It is assumed that the gravitational field surrounding a particle is equivalent to a strain or distortion of that portion of Minkowski's space-time world, and that the orbit due to gravitational action of a second particle about the first is a path

* In mathematical language, a vector which is parallel to the vertical axis OZ for Perth, has components along the vertical axis OZ and the horizontal axis OY at Sydney, and components along the axes OZ and OX for Roebourne.

through the distorted medium which would be straight if the distortion were removed. Einstein has found that on this theory a modification is necessary in Newton's law of gravitation. One form of Newton's law is that expressed in Laplace's potential function, but this form cannot be applied to such a force as centrifugal force. To get uniformity of treatment of all varieties of force a modification is needed of the gravitational law from the statement as originally given by Newton. Einstein has put forward a modified law which is indistinguishable from Newton's law in its effects in all but a few crucial tests: that is to say, the modification has not upset in the slightest any of our customary deductions from the old form of the law of gravitation. On the other hand, using the old form of the law the motion of that point of the planet Mercury's elliptical orbit round the Sun which lies nearest to the Sun was calculated to undergo a movement of 8 minutes 52 seconds of arc per century. Observation, however, showed the movement to be at the rate of 9 minutes 34 seconds, and Einstein's modification of the gravitational law has altered the calculated value to 9 minutes 35 seconds. Briefly put, Einstein's theory has not upset one of the innumerable cases where the old law was in agreement with fact; it has brought agreement in one case (that of Mercury) where grave discrepancy existed, and in at least one case it has brought closer agreement than could previously be obtained.

The forthcoming solar eclipse of 29th May, 1919, will afford an occasion for further testing Einstein's theory. The Sun during totality will be in the constellation Taurus, and if photographed will be obtained surrounded by certain stars to the north of the Hyades group. Now on Einstein's theory light has not only inertia but has weight, that is to say, is subject to gravitational attraction. Accordingly, rays of light coming from stars A and D (see diagram) will be deviated at P' and Q' so that they appear to come from stars situated at A' and D'. These stars will therefore appear to be not merely a solar diameter PQ apart, but at a rather greater separation $P'Q'$, and stars at B and C, which would otherwise be occulted by the intervening Sun will be visible at the Sun's limb. On Einstein's theory a distortion of 1·75 secs. of arc would be expected from stars such as A or D. If no distortion is recorded we shall have the strange result of light possessing mass but not weight, while a distortion of say 0·8 seconds would upset Einstein's theory but would show that light was subject to gravity. Davidson and Cortie will observe the eclipse from Sobral in Brazil, while Cottingham and Eddington will be stationed on Principe Island off West Africa. The probable meteorological conditions are not too favourable, and at the best some time will elapse before the photographic plates have been fully measured and compared with others of the same stars taken when the sun has moved away from the group. The results will be awaited with great interest by all scientists.



[Note added 9th September, 1919.—Reports to hand indicate that the eclipse was observed under fairly favourable conditions. The astronomers are, however, waiting on to obtain photographs of the same stars after the sun has moved away from these stars. By thus having the two sets of photographs taken with the same instruments in the same positions, possible instrumental errors will be reduced to the lowest minimum.]

[Note added 17th January, 1920.—At the joint meeting of the Royal and Royal Astronomical Societies held in London on 6th November, 1919, the Astronomer-Royal (Sir Frank W. Dyson) announced that the eclipse observations supported Professor Einstein's hypothesis. One of the Sobral cameras and that used at Principe —both of which produced sharp photographs—gave about 1.8 seconds of arc as the distortion of rays of light at the sun's edge. The second Sobral camera, despite its unsatisfactory performance, indicated a distortion greater than 0.8 seconds. The only other practical test of Einstein's theory which has been suggested, but not yet confirmed, is a displacement of spectral lines towards the red in the spectrum of a luminous body of great gravitative power.]